



Effect of harvest maturity on quality of fresh-cut pear salad[☆]

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ABSTRACT

Texture of an unripe pear is firm and crisp, similar to an apple. However, at the crisp stage, the flavor of pears is flat. This study evaluated the effect of harvest maturity on the quality of fresh-cut pear salad. Fruit were harvested at commercial maturity and 1-month delayed. After 2 and 5 months (1 and 4 months for delayed-harvest fruit) storage at -1°C , fruit were sliced into 8–12 wedges per fruit, dipped in an antibrowning solution, packaged in Ziploc bags and stored at 1°C for up to 21 d. Delayed-harvest fruit were larger in size ($\approx 20\%$ increase in weight), had lower flesh firmness ($\approx 17\%$ decrease), lower titratable acidity content ($\approx 20\%$ decrease), and lower phenolic content ($\approx 45\%$ and 13% decreases in pulp and peel, respectively). There was no significant difference in soluble solids content. After 2 months storage, ethylene production and respiration rate were initially lower in the slices from delayed-harvest fruit, but tended to become similar after 7 d in storage at 1°C . Delayed-harvest fruit had lower hydroxycinnamic acids and flavanols, and higher ester, alcohol, and aldehyde volatile compounds after 2–5 months storage. The results indicated that fruit salad produced with delayed-harvest pears had less browning potential and better flavor. Sensory evaluation results showed that about 80% of the panel liked slices from delayed-harvest fruit over commercial harvested, especially in terms of visual quality (65–85%), sweetness (75–95%), taste (70–80%), and overall quality (75–80%) during 21 d storage at 1°C . The cut surface of slices appeared dry in delayed-harvest fruit when processed after 5 months in storage. However, sensory evaluation showed that panels still preferred the delayed-harvest fruit.

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1. Introduction

Research on fresh-cut pears has focused on developing antibrowning solutions and on modified atmosphere packaging for partially ripened fruit to produce a product with typical pear flavor and an adequate shelf life (Buta and Abbott, 2000; Chen et al., 2003; Dong et al., 2000; Gorny et al., 1998, 2000, 2002; Rosen and Kader, 1989; Sapers and Miller, 1998; Senesi et al., 1999; Soliva-Fortuny et al., 2002a,b, 2004). However, once pear ripening is initiated, fruit rapidly lose flesh firmness (FF); usually FF decreases from over 50 Newton (N, unripe) to below 20 N (full ripe) in 2–3 d (Chen et al., 2003). Therefore, it is difficult for the industry to maintain a proper ripening stage on a commercial scale. Furthermore, “par-

tially ripe” is not a precise definition. It has been used differently by different scientists for different varieties. For example, Gorny et al. (2000) partially ripened ‘Bartlett’, ‘Bosc’ and ‘Anjou’ to 27–45 N, but ‘Red Anjou’ to 65 N; Soliva-Fortuny et al. (2004) indicates that 44 N is partially ripe for ‘Conference’ pears, and Chen et al. (2003) suggested that a FF of 22–31 N is proper for fresh-cut use of ‘Anjou’ pears. Partially because of such difficulties and confusions, fresh-cut pears are rare items in grocery stores and service industries. One problem with slices from riper fruit is that they are soft, and not easy to handle, store and ship.

On the other hand, fresh-cut apple production has increased rapidly in recent years. National and international restaurant chains are adding fresh-cut apple products to their menus. Major grocery chains sell sliced apples in bags or in fruit salad mixtures. Unripe pears are similar to apples in many ways: both are pome fruit, grow in similar climates, have similar firm and crisp textures, and thus, fresh-cut pears are a potential alternative to fresh-cut apples. Using less or “partially” ripe pears, the fresh-cut process and quality control of pear slices would be much easier to manage, and the product would be adequately firm for handling and shipping.

The problem is that at a crisp stage of ripeness, the flavor of pears is flat compared to apples and the texture of unripe pears is usually rough and lacks juiciness. Improving the flavor and texture

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of pears is considered to be the key to successful marketing of fresh-cut pears. One of the considerations to improve the fresh-cut pear quality is to delay harvest. Harvest maturity of pears is commercially determined by FF. The ideal harvest maturity is a FF of 58–67 N for 'Anjou' pears which allows the fruit to grow to a proper average size and be suitable for long-term storage as characterized by a juicy and buttery texture upon ripening (Chen and Mellenthin, 1981; Hansen and Mellenthin, 1979). The firmer fruit are usually destined for long-term and controlled atmosphere (CA) storage. On the other hand, softer fruit are selected for short-term storage. However, because ripening is not an issue, this traditional harvest maturity may not be suitable for fresh-cut pears. Preliminary experiments showed that when pears were left on the tree for an extended period past traditional harvest maturity, fruit continued to grow at a rate of 3–6% per week, and FF decreases at a rate of about 2–4 N per week. These fruit had desirable crunchiness, more juiciness, finer texture, richer flavor, and less browning (data not shown). As a drawback, delayed-harvest fruit were more susceptible to decay (Boonyakiat et al., 1987), therefore an enhanced decay control program is needed for delayed-harvest fruit.

'Anjou' is the principal fresh market pear cultivar in the United States with a pack-out of ~250,000 tonnes annually. Under proper conditions, 'Anjou' can be stored as long as 9 months. This cultivar also has less pre-harvest drop problems compared to other pear cultivars, which makes it possible to be harvested much later than current commercial harvest. 'Anjou' pears cannot ripen after harvest until the chilling requirement has been met by cold storage for about 2 months (Chen and Mellenthin, 1981; Chen et al., 1997). During cold storage, 1-aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase activities are induced, ACC is accumulated and onset of climacteric rise of ethylene production and ripening begin within 2–3 d upon transfer of fruit to room temperature (Agar et al., 2000; Chen et al., 1997; Wang et al., 1985). Generally, 'Anjou' and other European pears are consumed after ripening in the United States and European countries, however, the fruit are consumed in many other countries at the unripe stage.

In this research, fresh-cut 'Anjou' pears for pear salad from fruit harvested at the traditional maturity were compared to fruit harvested later (delayed harvest), analyzing chemical, physical and sensory quality characteristics.

2. Materials and methods

2.1. Plant materials and treatments

Six uniform mature pear trees (cv. Anjou on OH × F 97 rootstock (16-year old)) were selected from a pear block located at Mid-Columbia Agricultural Research and Extension Center, Hood River, Oregon. Three out of the six trees, representing three replicates were harvested on 31 August at commercial maturity and another three were harvested on 30 September as 1-month delayed harvest. Fruit from each tree were harvested separately and packed into 20-kg wooden boxes with perforated polyliner. Intact fruit quality attributes were analyzed at harvest, and after 2 months (1 month for delayed-harvest fruit) and 5 months (4 months for delayed-harvest fruit) at -1°C . One box of fruit from each tree was used every sampling time to represent one replicate. Sub-samples of 15 fruit from each box were used for fresh-cut processing on 30 October (after 1–2 months storage) and 31 January (after 4–5 months storage).

2.2. Fresh-cut process

Processing was conducted in a 20°C room. Fruit were washed in tap water ($5\text{--}13^{\circ}\text{C}$), then sanitized for 120 s in a 1°C solution of

$100\ \mu\text{L L}^{-1}$ sodium hypochlorite at pH 6.5, drained for about 600 s, and hand-cut to 8–12 wedges with a sharp stainless steel knife. After removal of the seed cavity, the slices, ~25 g each, were placed into colanders and immediately dipped for 30 s in an aqueous solution (1°C) containing 1% ascorbic acid, 0.8% calcium propionate, and 0.4% acetylcysteine for reducing browning and maintaining firmness (Bai et al., 2004). Fifteen fruit were used each sampling time. The slices pooled for each replicate were then allowed to drain for 1 h at 1°C before placement into 8 Ziploc polyethylene bags ($17.3\text{ cm} \times 20.3\text{ cm}$, thickness $30\ \mu\text{m}$, Western Family Foods, Portland, OR), 10 slices per bag, and stored at 1°C for up to 21 d. Gas concentrations in the bags, respiration rate, ethylene production rate, and quality attributes of the slices were determined at day 0, 7, 14 and 21 during storage. Two bags of slices per replicate were used each sampling day, one for sensory evaluation and another for analytical measurements.

2.3. CO_2 , O_2 and ethylene analysis

Headspace gas samples in the bags were taken using a 5-mL syringe and then injected into a gas chromatograph (GC). Hewlett-Packard 5890 II (Avondale, PA) equipped with a TCD and an HP MS-5a column, $30\text{ m} \times 0.53\text{ mm i.d.}$, $50\ \mu\text{m}$ coating (Hewlett-Packard, Avondale, PA) for O_2 and CO_2 analyses, and a FID and an Alltech AT-Q column, $30\text{ m} \times 0.53\text{ mm i.d.}$, $20\ \mu\text{m}$ coating (Alltech Associates, Inc., Deerfield, IL) for ethylene analysis. Samples were run isothermally ($T = 50^{\circ}\text{C}$) and quantification performed with calibration standards 21 kPa O_2 (air), 1 kPa CO_2 , and 5 Pa ethylene.

2.4. Quality parameters

Fruit size (diameter, length and weight) was measured directly after harvest by averaging 40 fruit over 3 replicates.

For respiration and ethylene production rates, 10 pear slices were removed from a bag to a 1-L sealed glass jar, and incubated for 1800 s. Well-mixed headspace gas samples were obtained from the jar, and analyzed by GC under the conditions described above. For intact fruit, 5 fruit were incubated in a 3.8-L glass jar for 3600 s.

Color of entire fruit and cut surface was based on CIE L^* , a^* , b^* , Chroma (C^*) and hue angle (h°) values using a white tile-calibrated Spectrophotometer (model CR-2500d, Minolta, Tokyo, Japan). The setting conditions were as follows: Mask/Gloss-M/SCI; UV Setting-UV 100%; Illuminant 1-D65 (standard); Illuminant 2-D-65; Observer-10°. The cut surface of 10 slices were measured per replicate bag.

Firmness was determined using a texture analyzer (Model GS-14, Guss Manufacturing Ltd., Strand, South Africa) with an 8-mm plunger that penetrated 9 mm in 54 s. For whole fruit, 10 fruit were used per replicate. Two measurements were obtained per fruit from opposite sides where 16-mm diameter peel discs were removed. For cut slices, a 10-mm thick piece was obtained from the equatorial part of the wedge. Ten slices were measured per replicate bag, and the firmness was expressed in Newton (N).

Fruit juice was prepared for soluble solids content (SS), titratable acidity (TA) and volatile measurements using a juicer (Model 6001, Acme Juicer Mfg Co., Sierra Madre, CA) with a milk filter (Schwartz Manufacturing Co., Two Rivers, WI) at about $2500\text{--}3000 \times \text{g}$.

SS was measured with a refractometer (Model N1, Atago, Tokyo, Japan). Titratable acidity was determined by titrating a mixture of 10-mL juice and 40-mL ion-free water with 0.1 mol L^{-1} NaOH to pH 8.1 using a titration system (Model T80/20, Schott-Gerate, Hofheim a. Ts., Germany), and calculated as concentration of H^+ .

For headspace volatile analysis, 1.5-mL fruit juice was homogenized with 0.75 mL deionized water and 0.75 mL saturated NaCl_2 solution in a 10-mL glass vial and sealed with a crimp-topped

Teflon–silicone septum, flash frozen in liquid nitrogen and stored at -80°C prior to analysis. Frozen samples were later thawed under running tap water, then using an autosampler (Gerstel US, Baltimore, MD) the samples were incubated in an agitator at 500 rpm and 40°C for 120 s before the headspace sample (1 mL) was taken from the vial and injected into a GC (Model 6890, Agilent, Palo Alto, CA) equipped with a $30\text{ m} \times 0.25\text{ mm}$ i.d. polar Stabilwax capillary column ($1.0\text{-}\mu\text{m}$ film thickness, Restek, Bellefonte, PA) and a flame ionization detector (FID), and a mass spectrometer (MS, Model 5973N MSD, Agilent). The GC conditions were: oven temperature held at 40°C for 360 s, then raised to 180°C at a rate of $0.1^{\circ}\text{C s}^{-1}$. The injection port and detector were kept at 250 and 280°C , respectively. The MS had an ionization energy of 70 eV and scanned from 45 to 250 m/z .

For phenolic compound analysis, 10 entire fruit per replicate were used. First, peel (thickness 1–2 mm) was obtained using a stainless steel vegetable peeler. Then pulp was obtained by removing the cavity tissue. 100 g of peel and pulp tissues per replicate from the pooled shreds were flash frozen in liquid nitrogen and freeze-dried. Ground, dry samples (1 g) were transferred into a 150-mL beaker containing ethanol–HCl solvent (85:15 ethanol/0.1N HCl), and heated to boiling for 60 s. After cooling, the supernatant was filtered through Whatman #4 filter paper for further analysis. Total phenolic contents were determined according to the Folin–Ciocalteu procedure (Slinkard and Singleton, 1977) using *p*-coumaric acid as a standard. Phenolic composition was analyzed with a Waters (Milford, MA) Alliance high-pressure liquid chromatography system, equipped with a Waters 996 PDA detector and a Waters/Micromass ZQ single-quadrupole mass spectrometer. Separation of the phenols was accomplished on a $250\text{ mm} \times 4.6\text{ mm}$ i.d. RP-Amide C16 (Supelco) column, with multistep linear water/acetonitrile/2% formic acid gradients at flow rates of $12.5\text{ }\mu\text{L s}^{-1}$. Initial solvent conditions were 85:10:5 (water/acetonitrile/2% formic acid), which increased in linear gradients to 81:14:5 in 900 s, to 77:18:5 at 1200 s, to 70:25:5 at 1800 s, to 40:55:5 at 3300 s, and to 0:95:5 at 4020 s. The solvents were then held isocratic at 0:95:5 for 780 s. The chromatograms were recorded at 285 and 320 nm. PDA detection was monitored between 230 and 600 nm. Data handling was done with MassLynx Software Version 3.5 (Micromass, Division of Waters Corp., Beverly, MA). The postcolumn split to the PDA and mass ZQ detector was 10:1. MS parameters were as follows: ionization mode, ESI+; capillary voltage, 3.0 kV; extractor voltage, 5 V; source temperature, 100°C ; desolvation temperature, 225°C ; desolvation N_2 flow, 129 mL s^{-1} ; cone N_2 flow, 19 mL s^{-1} ; scan range, m/z 150–900; scan rate, 1 scan s^{-1} ; and cone voltages, 20, 40, and 60 eV.

2.5. Sensory analysis

Sensory analysis was carried out by an experienced panel of 20 members using a paired comparison test for visual quality, texture, sourness, sweetness, flavor, and overall preference. Every panel member was presented with two samples, commercial harvested and delayed-harvest pears (two slices each) with a unique random code. For each attribute, the panel recorded the code for the sample they preferred.

2.6. Statistical test

SAS Version 9 (SAS Institute, Cary, NC) was used for analysis of data. Cut surface color, firmness, respiration rate, ethylene production rate, volatile concentrations and phenolic compounds were analyzed using the two independent samples *t*-test (PROC TTEST). Sensory evaluation data were analyzed using Fisher's exact test (PROC FREQ).

Table 1

Attributes of 'Anjou' pears harvested at commercial maturity or 1-month delay

Attribute	Commercial	Delayed	<i>t</i> -Test ^a
Fruit size			
Diameter (mm)	72.15	76.00	0.05
Length (mm)	95.15	95.50	NS
Weight (g)	233	279	0.05
Flesh quality			
Flesh firmness (N)	66.4	55.2	0.05
Soluble solids content (%)	12.7	12.6	NS
Titrateable acidity (H^+ , mmol L^{-1})	63	52	0.01
Respiration and ethylene production rates (20°C)			
CO_2 ($\text{nmol kg}^{-1} \text{s}^{-1}$)	32.2	29.8	NS
Ethylene ($\text{pmol kg}^{-1} \text{s}^{-1}$)	0	0	NS
Surface color (Minolta)			
L^*	62.62	64.28	0.05
a^*	−8.12	−7.29	0.05
b^*	37.32	38.69	0.05
C^*	38.21	39.37	0.05
hue angle ($^{\circ}$)	102.29	100.68	0.05
Total phenolic content (g kg^{-1}; dry weight basis)			
Peel	13.4	11.6	0.05
Pulp	4.7	2.6	0.01

^a NS, 0.05 and 0.01 represent no significant difference or significant level at 0.05 and 0.01, respectively.

3. Results and discussion

3.1. Quality attributes at harvest

Delayed-harvest fruit were about 20% heavier than commercially harvested, with a larger diameter (Table 1). Rate of fruit growth after commercial harvest is different year to year. According to our observations, 'Anjou' pears grow about 2–6% weekly after commercial maturity. Fruit grow faster in warm and wet weather and slower in cool, dry weather (data not shown). The increase in weight was mainly contributed to by an increase in the diameter of the fruit (Table 1) as a result of cell enlargement (Sugar et al., 2000). This indicates a potential economic return (9–27% increase in a month) for growers.

Average fruit firmness at commercial harvest time was 66.4 N and decreased to 55.2 N after a 1-month delay in harvest (Table 1). Firmness is the most reliable indicator for determining the maturity of 'Anjou' pears (Chen and Mellenthin, 1981; Hansen and Mellenthin, 1979). Fruit normally lose firmness by 2–4 N per week after commercial harvest maturity and warm and wet weather exacerbates softening (data not shown). For traditional use of pears, delayed-harvest pears usually have a short storage life. Chen and Mellenthin (1981) reported that 2 and 3 weeks delayed-harvest 'Anjou' pears had mealy (poor) texture upon ripening after storage of 3 months or longer. Sams (1999) suggested that large fruit, which have the same number of cells as smaller fruit (but the cells are enlarged), have a smaller percentage of their volume in cell wall material. Thus, tissue density would be lower. During fruit ripening, pectins (Fischer and Bennett, 1991) and hemicelluloses (Wakabayashi, 2000) typically undergo solubilization and depolymerization that are thought to contribute to cell wall loosening and disintegration. Murayama et al. (1998) compared softening of 'Marguerite Marillat' and 'La France' pears on and off the trees after commercial harvest, and found that the amount of water-soluble polyuronides increased slightly during softening of fruit on the tree, but increased three times or more in fruit softened off the tree. Therefore, in this research, decrease of FF by delaying harvest is likely caused by cell enlargement, with little or no involvement of cell wall material degradation.

Table 2

Effect of harvest maturity and storage time on phenolic composition in peel and pulp of 'Anjou' pears

Elution time	UV characteristic	MS ions	Possible structure	Peak area					
				1–2 month(s) storage			4–5 months storage		
				Commercial	Delayed	<i>t</i> -Test ^a	Commercial	Delayed	<i>t</i> -Test
Peel									
17.77	H ^b			48,895	49,276	NS	47,065	39,308	NS
18.67	H			30,039	30,681	NS	34,538	31,721	NS
28.67	H			5,971	6,396	NS	4,870	3,632	0.05
29.40	H			4,586	5,001	NS	4,826	3,533	0.05
30.57	H			3,238	2,699	0.05	1,971	1,603	NS
31.47	H			10,466	8,306	0.05	7,282	4,813	0.01
39.30	H	163/303/499/551	P ^c	3,476	2,784	NS	9,036 ^d	10,170 ^d	NS
34.15	F	303/465/611	P, G, R	6,332	4,770	NS	4,006	5,573	0.05
36.20	F	303/317/625/649	T, M	6,529	4,929	0.01	5,339	4,636	NS
36.50	F	317/479/625/647	T, M, G, R	5,693	4,691	0.01	4,851	4,323	NS
37.03	F	317/479/625/647	T, M, G, R	5,806	4,569	0.05	3,922	3,898	NS
38.60	F	317/479	T, M, G	4,743	2,850	0.01	1,845	2,968	0.05
39.50	F	303/551/573	P	7,395	6,123	0.05	(Combined)	(Combined)	
42.50	F	317/565/587	T, M	5,517	4,381	0.05	2,959	3,654	NS
43.10	F	303/354/579/601	P	1,341	1,043	0.05	1,123	1,267	NS
Pulp									
17.77	H			15,562	9,601	0.01	16,982	9,293	0.01
18.67	H			10,430	6,510	0.01	15,533	10,293	0.01
30.57	H			1,763	718	0.01	1,093	0	0.01
31.47	H			4,614	2,318	0.01	2,690	2,423	NS

Commercially harvested fruit were stored for 2 or 5 months, and 1-month delayed-harvest fruit were stored for 1 or 4 month(s) at -1°C .^a *t*-Test: NS, 0.05 and 0.01 represent no significant difference or significant level at 0.05 and 0.01, respectively.^b H: hydroxycinnamic acids; F: flavanols.^c P: pentahydroxyflavone; G: glucose; R: rhamnose; T: tetrahydroxy; M: monomethoxyflavone.^d Peak was not separated from the peak at elution time 39.5 min.

Titrateable acidity content was lower in delayed-harvest fruit than in commercially harvested fruit (Table 1). However, there was no difference in soluble solids contents between commercially harvested and delayed-harvest fruit (Table 1). This is because that by keeping fruit on trees, sugar was accumulated, and nevertheless, the growth in size diluted the increase of sugar. Because the delayed-harvest fruit had higher ratio of sugar/acidity compared to commercially harvested fruit, sweeter tasting fruit could be expected.

Respiration rate at harvest measured by CO_2 production was 32.2 and 29.8 $\text{nmol kg}^{-1} \text{s}^{-1}$ for commercially harvest and delayed-harvest fruit, respectively (Table 1). There was no difference between treatments. Fruit at harvest did not produce ethylene regardless of harvest maturity (Table 1), because pears require a chilling period after harvest to stimulate synthesis of ACC, the immediate precursor of ethylene (Agar et al., 2000; Chen et al., 1997; Wang et al., 1985).

Delayed-harvest fruit also had greater L^* , b^* and a^* color values as well as smaller hue angle, indicating degreening and/or yellowing of the fruit surface color (Table 1). Chroma (C^*) was slightly but significantly higher indicating brighter color.

We analyzed phenolic compounds in peel and pulp, and found that the total phenolic content (TPC) of the peel was three- to fourfold higher than in pulp (Table 1). TPC significantly decreased by delayed harvest partially due to the enlargement of the fruit (Table 1). Since the Folin-Ciocalteu methodology was used to analyze total phenolic content, other easily oxidized substances other than phenolic compounds are possibly quantified in the determination. This could lead to an overestimation of the TPC for all samples. Based on the close spectral similarities of compounds detected by HPLC with known hydroxycinnamic acids and flavones, extracts of the pear peel analyzed in this study contained seven hydroxycinnamic acids and eight flavanol conjugates (Table 2). In contrast, only four hydroxycinnamates were detected in the pulp, and no flavanol conjugates (Table 2). The UV spectra and the anal-

ysis of the phenols in the peel by HPLC-MS provided additional structural information concerning these compounds. The observed molecular weights and fragmentation patterns in the mass spectra of these compounds suggest that these flavanols include four possible pentahydroxyflavone (detected by the m/z 303 ion) and four tetrahydroxy-monomethoxy flavone (detected by the m/z 317 ion) glycosides (Table 2). The most common pentahydroxy- and tetrahydroxy-monomethoxy flavones include quercetin and rhamnetin, respectively. Delayed-harvest fruit, both in peel and pulp, contain significantly less hydroxycinnamic acids and flavanols (Table 2), indicating that fruit harvested late have less browning potential upon cutting. Pears are an excellent source of phenolics and, therefore, possess an extremely high antioxidant capacity. The measured phenolic antioxidant capacity of 20 different fruit ranked pear second only to cranberry in the assay on the basis of serving size (Vinson et al., 2001).

3.2. Gas combination in packages and respiration and ethylene production of cut slices

The oxygen partial pressure in the Ziploc bags with cut slices remained at about 20 kPa during the entire storage period at 1°C , regardless of fruit harvest maturity (Fig. 1A). CO_2 partial pressure increased to 1.1–1.4 kPa in the bags after 1 week storage and then stabilized, however, there was no significant difference between treatments (Fig. 1B). Under such atmosphere with a slight modification of CO_2 , cut fruit generally maintain a regular metabolism (Bai et al., 2004). Ethylene partial pressure in the bags accumulated to 0.5–0.6 Pa in the first week, gradually increased and the final concentration was about 0.8 Pa after 3 weeks storage (Fig. 1C). There was no difference between commercially harvested fruit and delayed-harvest fruit. Because the storage temperature was as low as 1°C , the impact caused by ethylene was very limited (Chen and Mellenthin, 1981). The respiration rates of slices were 3.8–5.5 $\mu\text{L kg}^{-1} \text{s}^{-1}$ during storage with no significant difference

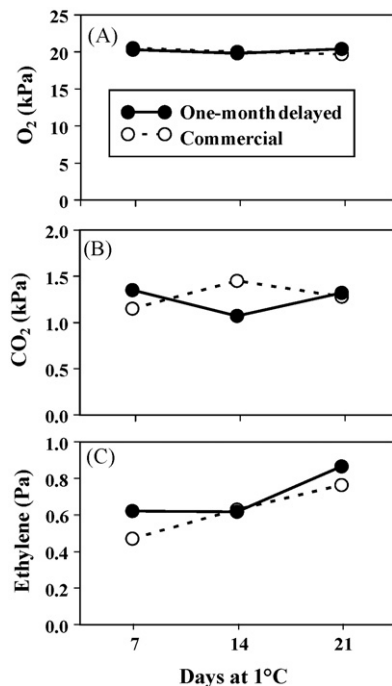


Fig. 1. Oxygen, CO_2 and ethylene concentrations in packaging of pear slices during storage at 1 °C ($n=3$). Commercially harvested fruit were stored for 2 months, and 1-month delayed-harvest fruit were stored for one month at –1 °C before cutting.

between treatments (Fig. 2A). Slices from commercially harvested fruit had higher ethylene production in the first week, but exhibited similar levels as delayed-harvest fruit throughout the rest of the storage period (Fig. 2B). According to Agar et al. (2000), and Chen et al. (1997), 1-aminocyclopropane-1-carboxylic acid (ACC) level, and activities of ACC synthase and ACC oxidase increased with increased length of cold storage. This may explain why commercially harvested fruit were stimulated to produce more ethylene in response to cutting. There was no climacteric rise in respiration and ethylene production during storage due to low storage temperature. It takes 2–3 d at room temperature for cold stored 'Anjou' fruit to start the climacteric rise of ethylene and respiration (Chen et al., 1997). The results indicate that the basic respiratory metabolism of cut slices was similar for both harvest maturities.

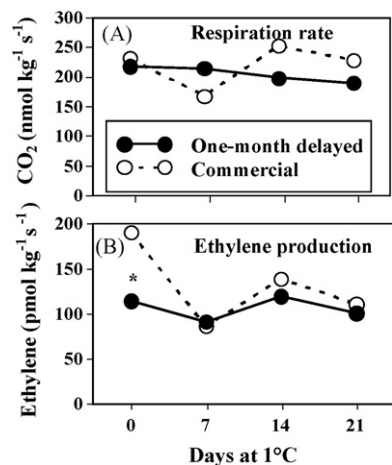


Fig. 2. Changes of respiration and ethylene production rates of pear slices during storage at 1 °C ($n=3$). Commercially harvested fruit were stored for 2 months and 1-month delayed-harvest fruit were stored for 1 month at –1 °C before cutting. * represents a significant separation in same sampling day at 0.05 level using *t*-test.

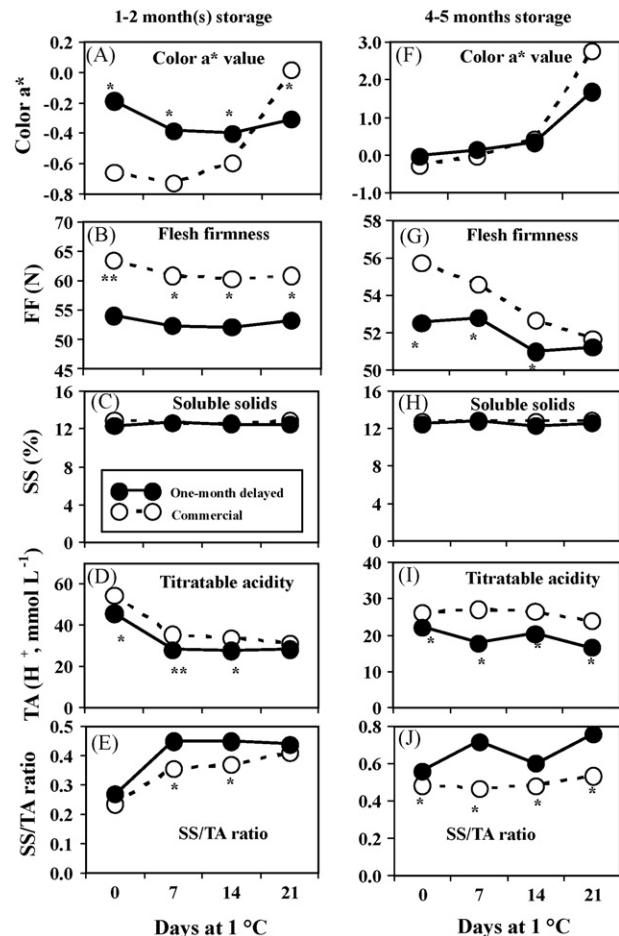


Fig. 3. Changes of CIE a^* value on cut surface, flesh firmness, soluble solids (SS) content, titratable acidity (TA) content, and SS/TA ratio of pear slices during storage at 1 °C ($n=3$). Commercially harvested fruit were stored for 2 or 5 months, and 1-month delayed-harvest fruit were stored for 1 or 4 month(s) at –1 °C before cutting. ** and * represent a significant separation in same sampling day at 0.01 and 0.05 level using *t*-test, respectively.

3.3. Quality characteristics

Slices from delayed-harvest fruit had lower contents of hydroxycinnamic acids and/or flavanols in both peel and pulp (Table 2). As a consequence, slight browning of the cut surface appeared after 3 weeks shelf life in commercially harvested fruit stored for both 2 and 5 months prior to cutting, indicated by a positive a^* value (Fig. 3A and F). After 1–2 months storage, slices from delayed-harvest fruit had higher a^* values than slices from commercially harvested fruit initially, but the values were still in the negative range, indicating that the flesh was less green (but not brown) in comparison with commercially harvested fruit (Fig. 3A). The negative value remained throughout the shelf life (Fig. 3A). After 4–5 months storage prior to cutting, the a^* value of the cut surface was about 0 and remained stable during first 2 weeks, but increased afterward without a significant difference between different harvest maturities (Fig. 3F). As sensory evaluation results for visual quality showed, the panel preferred delayed-harvest fruit over commercially harvested fruit after both 1–2 and 4–5 months storages (Fig. 4). After 4–5 months storage, the cut surface of slices appeared dry in delayed-harvest fruit. However, sensory evaluation showed that panels still preferred the delayed-harvest fruit.

A critical quality problem of fresh-cut 'Anjou' pears is poor texture. Without ripening, a commercially harvested pear has a rough

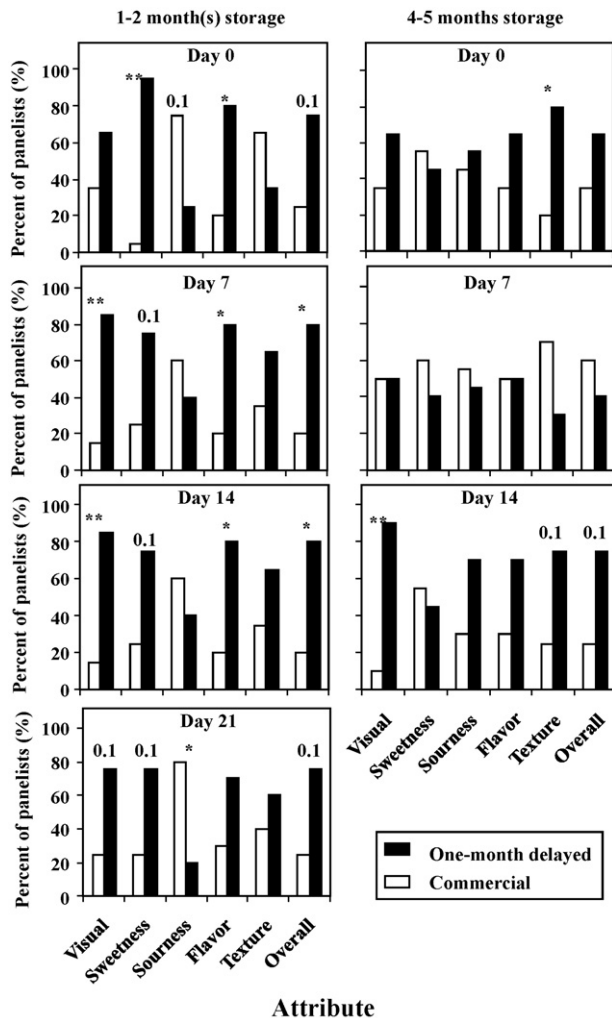


Fig. 4. Panel preference of sensory attributes of pear slices during storage at 1 °C (20 members). Commercially harvested fruit were stored for 2 or 5 months, and 1-month delayed-harvest fruit were stored for 1 or 4 month(s) at −1 °C before cutting. **, *, and 0.1 represent a significant separation in same sampling day at 0.01, 0.05 and 0.1 level using Fisher's exact test, respectively.

and dry flesh. By delaying harvest time, FF of cut slices decreased 4–6 N during shelf life (Fig. 3B and G), except for the fruit stored for 4–5 months followed by a 3 weeks shelf life of cut slices, where there were no differences in FF between different harvest maturities (Fig. 3G). FF decreased during shelf life when slices were from 4 to 5 months stored fruit, but FF maintained constant when slices were from 1 to 2 months stored fruit (Fig. 3B and G). The panel did not distinguish a difference in texture between the different harvest maturities when the fruit were stored 1–2 months prior to cutting (Fig. 4). However, after 4–5 months storage, 90% and 85% of panel preferred the slices from delayed-harvest fruit immediately after cutting and after 14 d of shelf life, respectively (Fig. 4). This indicates a complex correlation between analytical firmness and the consumer perception of texture (Figs. 3B and G, and 4). Firmness, as felt by teeth and mouth, is a sensitive and complex trait that requires more than simple compression analysis to measure (Bai et al., 2004).

There was no difference between commercial harvest and delayed harvest in SS content (Fig. 3C and H). SS content did not change during storage (Fig. 3C and H). However, TA content in delayed-harvest slices was low initially and decreased gradually during storage in comparison with slices from commercially har-

Table 3

Effect of harvest maturity on headspace volatile emission from cut slices of 'Anjou' pears

Compound	Peak area × 10 ⁴		t-Test ^a
	Commercial	Delayed	
Ethanol	96	104	NS
Propanol	43	58	0.05
Butanol	13	15	NS
2-Methyl-1-pentanol	7	5	NS
Acetic acid	16	18	NS
Propyl acid	196	216	NS
2-Propanoic acid	10	9	NS
Hexanoic acid	0	3	0.01
Ethyl acetate	9	10	NS
Propyl acetate	212	302	0.01
Butyl acetate	56	57	NS
Methyl iso-butyrate	4	5	NS
Hexyl acetate	8	14	0.01
Propanal	29	33	NS
(Z)-2-Heptenal	1	2	NS
Nonanal	4	3	NS
Total abundance	804	1023	0.05

Commercially harvested fruit were stored for 2 months, and 1-month delayed-harvest fruit were stored for 1 month at −1 °C before cutting and cut slices were stored at 1 °C for 7 d.

^a NS, 0.05 and 0.01 represent no significant difference or significant level at 0.05 and 0.01, respectively.

vested fruit (Fig. 3D and I). Thus, fruit from delayed harvest had a higher SS/TA ratio compared with commercially harvested fruit (Fig. 3E and J). The panel preferred delayed-harvest fruit over commercially harvested ones in sweetness (Fig. 4), reflecting that high SS and high SS/TA were preferred. However, the panel preferred commercially harvested fruit in sourness (Fig. 4), indicating that a higher sourness is not a negative taste factor. Delayed-harvest 'Anjou' pears contained higher amounts of esters, alcohols, acids, and aldehydes, especially the major volatiles such as propanol, propyl acetate, hexyl acetate, and hexanoic acid. The total abundance of volatile compounds increased 27% by delaying harvest for 1 month (Table 3). However, ripe fruit usually emit 10- to 100-fold more volatiles in comparison with unripe fruit (Baldwin, 2002; Kondo et al., 2006). Therefore, fresh-cut pear salad is a different product than ripe pears in terms of aromatic flavor: fresh-cut pear emit much less pear and fruity flavor than ripe pear products. The panel preferred delayed-harvest fruit over commercially harvested ones in flavor when processed into a fresh-cut product after 1–2 months storage (Fig. 4).

During 21 d shelf life, over 70% of panel preferred delayed-harvest fruit in visual appearance, sweetness, flavor and overall. The preference for delayed-harvest fruit was more significant when slices were evaluated directly after cutting and after 7 d of shelf life, and the difference decreased after longer storage (Fig. 4). Fruit harvested at commercial maturity were more sour; however, 60–80% of panel preferred the sourness. Conversely, when fruit were stored for 4–5 months before cutting, panel did not distinguish the difference between commercial and delayed-harvest fruit, except for texture immediately after cut, visual appearance, texture, and overall preference 14 d after cutting (Fig. 4). For overall preference, 75–95% panel preferred slices from delayed-harvest fruit after 2 months post-cutting storage, but the numbers were 70%, 45% and 80% after 5 months storage (Fig. 4). Therefore, the advantage of delaying harvest was mostly seen when fruit are sliced earlier after harvest.

4. Conclusion

We propose a new fresh-cut pear product, pear salad, which avoids complicated "partial ripening" process, and would be easy

to transport due to firm texture. To improve the quality of flat flavor, firm and rough texture, and high potential of browning, fruit were harvested 1 month later than the commercial norm, based on the positive results from this preliminary experiment. The results showed that by delaying harvest, the fruit had larger size, lower flesh firmness, lower titratable acidity, lower phenolic content and higher volatiles. The panel preferred the delayed-harvest cut fruit over those from commercial harvest, especially in terms of visual quality, sweetness, flavor, texture and overall quality.

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